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VISUALLY EVOKED BRAIN POTENTIALS AS AIDS IN DISPLAY DESIGN,(U)

AUG 77 R D O'DONNELL, R J SPICUZZA F33615-75-C-0127

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1 OF 1

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
18 19 AMRL-TR-77-58

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
6 VISUALLY EVOKED BRAIN POTENTIALS AS AIDS IN DISPLAY DESIGN.

5. TYPE OF REPORT & PERIOD COVERED
Presentation and proceedings

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
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8. CONTRACT OR GRANT NUMBER(s)
In part under
15 F33615-75-C-0127

9. PERFORMING ORGANIZATION NAME AND ADDRESS
*Aerospace Medical Research Laboratory, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio 45433

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
16 62202F, 7184-16-01 17 16

11. CONTROLLING OFFICE NAME AND ADDRESS
(same as block 9)

12. REPORT DATE
11 Aug[redacted]1977

13. NUMBER OF PAGES
12 11p.

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

DDC
RECEIVED
SEP 8 1977
A

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES
**Systems Research Laboratories, Inc., 2800 Indian Ripple Rd. Dayton, Ohio 45440
Prepared for presentation at the AFSC Science and Engineering Symposium, 28 Oct 1977 and for presentation at the Midcon 77 Electronic Show and Convention, 8-10 Nov 77, Chicago, Illinois, and publication in the Midcon Proceedings

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Human Engineering
Visual Displays
Evoked Response
Performance Measurement
Psychophysiology

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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evoked potential provides a unified metric that allows the engineering psychologist to assess the total requirements placed on the subject, from sensory input to motor output. Several studies are reported using this technique to answer questions of display design and operator performance. For the future, improvements in recording and analysis should allow this technology to move from the laboratory to the field, and permit rapid assessment of such subjective factors as fatigue, attention, psychological distress and other potentially dangerous operator states.

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ABSTRACT

The electrical activity of the brain in response to a visual scene is being used as an adjunct to measurement techniques in several human engineering and medical applications. Recorded from electrodes placed on the subject's scalp, this 'evoked potential' sensitively measures the way that the human responds to differing presentations of the outside world. It permits evaluation of the effects of changes in the sensory qualities of a displayed scene, as well as the cognitive demands and response requirements of a specific task. As such, the evoked potential provides a unified metric which allows the engineering psychologist to assess the total requirements placed on the subject, from sensory input to motor output. Several studies are reported utilizing this technique to answer questions of display design and operator performance. For the future, improvements in recording and analysis should allow this technology to move from the laboratory to the field, and permit rapid assessment of such subjective factors as fatigue, attention, psychological distress and other potentially dangerous operator states.

INTRODUCTION

The behavioral metrics typically used by engineering psychologists to assess man/machine interactions have proven their validity and reliability over many years of application. However, as the sophistication of operator systems increases, we find ourselves faced with the need to provide increasingly finer measurements in order to answer more and more complex questions. It is no longer adequate to decide that performance is or is not better with a given display or equipment design. Engineers and planners now need to know <u>why</u> a given system is different, so that they can intelligently determine tradeoffs with some other aspect of a complex design. In effect, it is necessary to adopt not only an <u>end-product</u> orientation with respect <u>to how well</u> the human can perform, but to enter intensively into the <u>process</u> involved in achieving a given level of performance. Behavioral measures such as reaction time, percent-correct, tracking describing functions, etc., enter into performance processes indirectly, if at all, and usually are applicable to a very narrow range of performance. What is needed as an adjunct to these techniques is a general, direct measurement of the subject's performance under a given system. Preferably, such a measurement technique should be able to reflect the subject's reactions to physical attributes of the system (size, shape, color, weight, etc.), cognitive demands imposed in interacting with the system (information processing, decision making, memory, etc.), and the motor requirements of the system (strength, speed, accuracy, etc. of the response required). This Utopian goal may never be achieved with a single metric. However, we believe that one technique, the evoked potential (E.P.) of the brain, approaches the above requirements, and promises a fertile field for future research and application.

The evoked potential is the electrical activity of the brain which is produced, or evoked, by a discrete event. In order to isolate this response, we typically expose the subject to a single stimulus, and simultaneously record the electroencephalogram (EEG). The brain's response to that stimulus is extremely small relative to the on-going background EEG, which can be considered "noise" in this context. This is an unfavorable signal-to-noise ratio which can be improved in several ways. The most common technique involves presenting the stimulus many times and averaging the EEG in a time-locked way immediately after each presentation. This reduces the randomly occurring EEG "noise" to a theoretical zero, and allows the real "evoked

potential" to be seen clearly. Typically, a strong stimulus will produce a clear EP with less than 32 stimulations. In the case of the visually evoked response, the EP will measure 10 to 20 microvolts peak-to-peak, and will develop from a background EEG of up to 200 microvolts. Since most of our applications thus far have involved visual stimuli, we will limit our discussion to the Visually Evoked Respone (VER). However, similar applications are being made for responses evoked from the auditory, tactile, and vestibular systems.[1]

The Transient Evoked Potential

An idealized visual response obtained by relatively slow repetition of the stimulus consists of several consistent peaks and valleys, usually identified sequentially as positive (P_1, P_2, etc.) or negative (N_1, N_2, etc.), or occasionally by the latency of the peak in milliseconds (e.g. P_3 or P300). This is called the transient evoked potential. It is possible to divide the VER into major segments which apparently are generated by different sources in the brain, and which are sensitive to different qualities of the stimulus condition (figure 1). The first major segment of the VER extends across the first 250 milliseconds or so of stimulation. This part of the waveform seems to be particularly responsive to manipulations of the physical attributes of the visual stimulus such as color, intensity, movement, or motion.[2,3,4] For example, the N_1 peak is extremely sensitive to the sharpness of a displayed image. If a checkerboard pattern is out of focus, this N_1 component will be diminished or absent.[1 5] Using this technique, many schools of optometry are now prescribing glasses for infants and others incapable of verbal response.

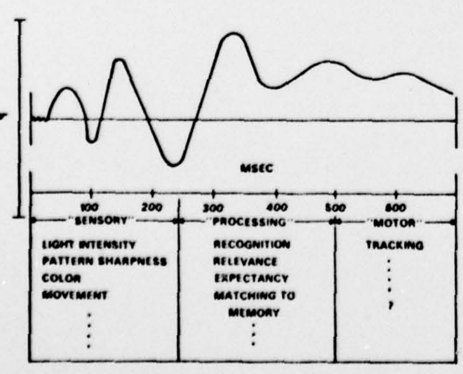

Figure 1. Visual Evoked Response

The second major segment of the VER extends from about 250 to 500 milliseconds, and seems to be exquisitely responsive to what has been called "processing sensitivity". In particular, one peak (the P_3 or P300) appears sensitive to changes in the information processing demands being made on the subject. Several studies have indicated that enhancement of this peak is uniquely associated with the occurrence or expectation of a signal, or with its correct detection.[1] The P300 varies predictably when we experimentally manipulate memory load, expectancy, a shift in a motor set, or detection of a threshold stimulus.[4] In this context, the P300 can be considered to reflect cognitive functions.

The last period of time in the evoked response, after 500 milliseconds, appears to represent the efferent firing involved in the motor response itself, or a muscle component of the response. As of yet, very little is known about this component of the EP, but it may well represent a less contaminated measure of actual response latency than traditional reaction time measures.

The Steady-State Evoked Potential

The transient evoked potential has been known for sometime, and forms the foundation of many current applications of EP technology. A different type of evoked response has been more recently described, however, which promises to be equally productive.[4] In this technique, the display is flashed very rapidly, between eight and twelve times per second. The EEG is recorded in the same way as for the transient evoked response. However, by appropriate filtering, only activity occurring at the stimulating frequency is considered. This results in an output which is identical, in the frequency domain, to the input frequency. In effect, this technique constrains a part of the brain's transmission process to achieve a "steady-state", and this is measured by the quality of the evoked potential at the input frequency. The EP parameters which can still vary with stimulus variations under this constrained situation are amplitude and phase angle. This introduces great consistency between subjects. Since these parameters are sensitive to very small changes in the stimulating environment, the measure provides a stable and reliable index of sensory processing. Using this technique, investiga-

tors have established that direct, objective measurements of both absolute and differential psychophysical thresholds can be obtained.[6] In addition, the technique mentioned above for prescribing glasses can be modified to utilize the steady state evoked response. Since the only thing varying with sharpness of the image is amplitude, a technician can now perform the test by simply observing a number indicating response amplitude, never having to view a waveform.

The Visual Response Facility

In view of these capabilities of the VER, and of the Air Force interest in providing objective measures of operator display quality, we have established a visual response facility in the Human Engineering Division of the Aerospace Medical Research Laboratory, Wright-Patterson AFB, Ohio. A schematic representation of the elements of this laboratory is presented in Figure 2.

Although the IAC chamber is available to provide RF shielding if necessary, the state-of-the-art in recording electrodes and amplifiers makes this unnecessary in most cases. Visual or other stimuli are introduced to the subject, and he or she may respond behaviorally or not, depending on the particular experiment. The EEG is recorded from scalp electrodes and passed through high impedence probes to high gain amplifiers. From there the signal is recorded on analog tape, and simultaneously may be processed through a PDP 11/35 computer or a hardwired Nicolet signal averager. Peripheral displays and other data handling apparatus permit great flexibility in the control, recording and analysis of experiments.

This laboratory allows us to record both transient and steady state evoked responses. The computer facility allows us to determine the precise relationship between the evoked response

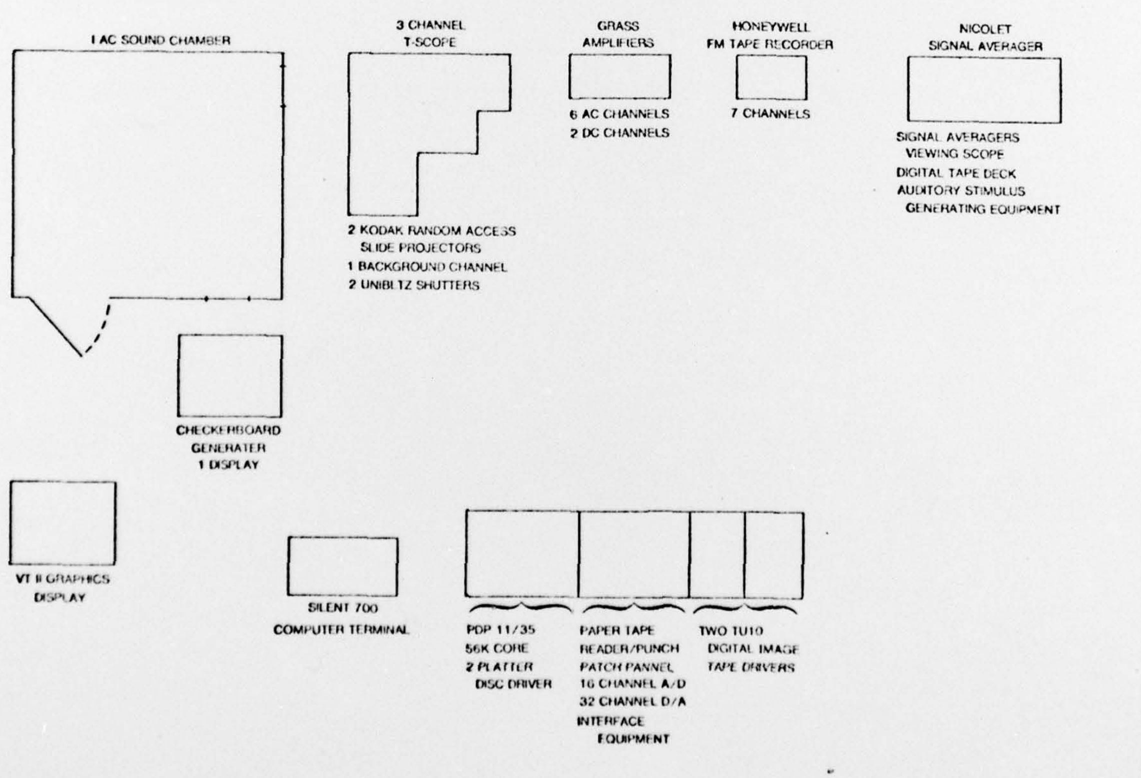

Figure 2. Components of the Visual Response Facility at Wright-Patterson Air Force Base.

and any behavior, such as reaction time or tracking, which may occur at the same time. We are capable of recording other psychophysiological measurements simultaneously in order to obtain additional correlates of behavior or brain activity. In addition, the laboratory possesses a Stanford Research Institute eye tracker which uses the fourth Purkinje image of an IR source reflected from the lens. This permits us to determine, within one minute of arc, precisely where the subject is looking. Together, these facilities provide a flexible and precise environment for conducting a wide variety of studies dealing with display design.

EXPERIMENTAL STUDIES

Effects of Information Processing Tasks

An early utilization of this facility involved studies designed to evaluate the information processing load imposed by the use of LED dot matrix alphabet letters in aircraft displays. There was a question concerning the degree to which such displays would force the operator to utilize an extra processing step in order to translate the dot symbol into a useable "Gestalt" in order to process it like a familiar stroke letter. Reaction time studies could reveal no difference between the two symbologies, but these were unconvincing since reaction time is such a notoriously variable measure. It was also possible that the subject was simply "working harder" to produce a good reaction time with the dot symbology. If this was the case, such a workload might lead to greater errors and more accidents. A significant engineering development program was being delayed until the processing sequence could be studied in more detail.

We performed two studies utilizing a complex reaction time paradigm to compare the subject's response to dot and stroke letters.[7] In addition, however, we also obtained transient evoked responses to the presentation of each symbology separately. Analysis revealed no reaction time difference in either study. For the VER, no peaks showed significant latency or amplitude differences except one. The one peak showing a difference was the P_2 peak, which is usually considered to correlate with the end of the encoding stage of information processing. (Fig. 3) In both studies, this peak was significantly later for the dot symbology as opposed to the strokes. In absolute terms, the difference measured between 4 and 10 milliseconds. In addition, this difference was "made up" by the next negative trough (N_2). Since none of the amplitude differences were significant between symbologies, it could be argued that this pattern of responses was not accompanied by an increase in workload on the part of the subject.

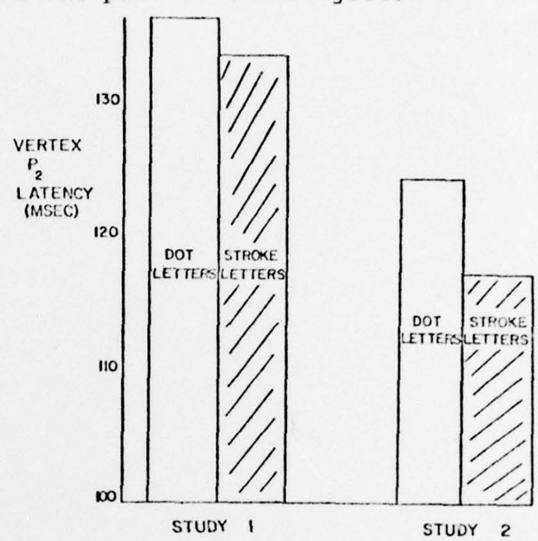

Figure 3. Vertex P_2 Latency in Msec. for two different symbologies.

This was the first instance, to our knowledge, of the VER being used specifically to answer a human engineering question involving actual display design. The net effect of these studies was to break the total reaction time into constituent parts. By doing this, we were able to show that a statistically significant difference did exist in processing of the visual stimulus, and we were able to interpret the meaning of the difference. In place of the unprovable negative result, we supplied a positive result. Because of the precision and confidence inherent in such a result, engineers were able to make an operational decision that the small time difference between symbologies would not lead to a genuine behavioral effect which would have unacceptable negative consequences on the operator.

Effects of Display Relevance and Workload

In a similar effort, we looked at the effects of cognitive "workload" and "meaning" on the VER.[8] Using a paradigm reported extensively by Sternberg, we required the subjects to

memorize letters of the alphabet. These were defined as "relevant" or positive-set items. All remaining letters of the alphabet were defined as non-relevant or negative-set letters. In some cases, one letter of the alphabet was positive, while in other cases the memory load was increased by making as many as eight letters of the alphabet positive. VER's were obtained to presentation of positive and negative-set letters separately for each memory load condition.

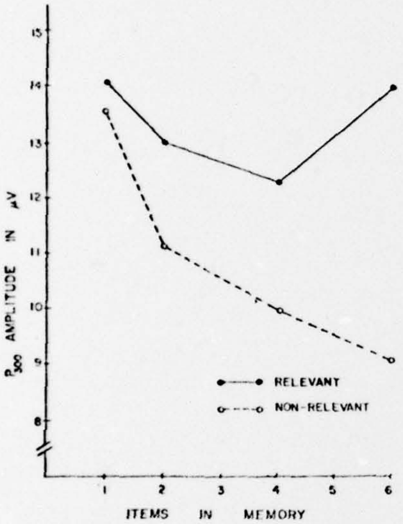

Figure 4. Amplitude of P300 as a Function of Symbol Relevance.

When we analyzed the P_3 wave, we found that the amplitude of the waveform induced by the "relevant" or positive-set items was routinely larger than that to the non-relevant items. (Fig. 4). This difference was larger under greater memory loads, and confirms many previous studies indicating that P_3 is extremely sensitive to the "meaning" of the stimulus. With this sensitivity, it should be possible to utilize this peak as an index of the ability of the subject to recognize and handle information presented in a display. Experiments currently being carried out by other investigators are confirming this expectation. It has been determined that the P_3 amplitude is significantly greater when the subject sees a familiar face as opposed to an unfamiliar one.

In addition to the above amplitude differences, we found that the latency of the P_3 varies directly with the memory load imposed, at least at these low levels.

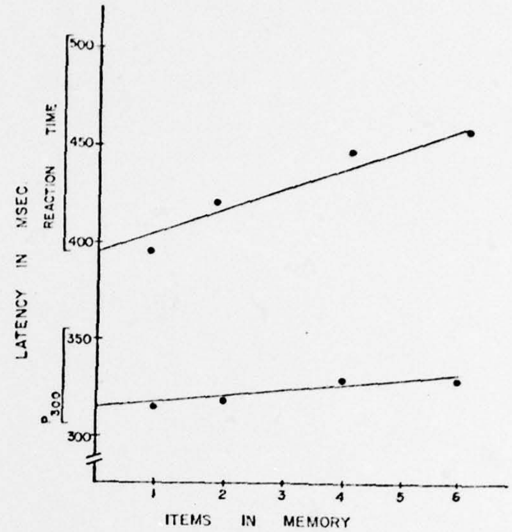

Figure 5. Reaction Time and P300 Latency for different Memory Loads.

Of course, reaction time also varies with memory load. However, the linear component of the function relating reaction time with memory load accounts for only 80 percent of the variance, with a strong quadratic component. Considering P_3 latency, the linear component accounts for 99 percent of the variance. We believe this indicates that the VER, by eliminating most of the motor variability inherent in the reaction time measure, provides a much more stable and reliable index of cognitive workload.

In another study, we compared the effects of a proposed aircraft camouflage paint scheme on recognition of aircraft attitudes by pilots. Reaction times of subjects viewing photos in different attitudes were not different with the differing paint schemes. Again, one could question whether the processes by which the subjects were responding in fact differed, even though they led to the same product; in this case, a reaction time. When we analyzed the VER to the various paint schemes and to aircraft attitudes, we found no major differences in amplitude or latency. This confirmed the reaction time results, adding more detail and credibility to the findings. It also confirmed subjective responses of no perception of differences between the two schemes. The subjects thought the stimuli were the same, and therefore they processed them in the same way.

Development of Design Standards

In another general class of investigation, we are exploring the possibility of utilizing the steady state evoked response to establish standards for optical distortion in such laminated substances as aircraft windscreens.[9] Distortion in such substances may be so small as to be subliminal, yet be sufficient to cause operator fatigue or performance disruption. While it may be possible to develop physical specifications for distortion, it is not easy to determine exactly which physical anomalies correlate with behavioral effects when such effects are subliminal. Because of its extreme sensitivity to the quality of the visual image, the steady state EP may pinpoint the exact anomalies which are ultimately resulting in disturbances. Efforts are currently underway to look at the EP response to known windscreen distortions, and to determine whether simultaneously recorded monocular steady state EP's will reveal a difference in phase angle or amplitude between the eyes indicative of early interocular rivalry and fatigue.

This type of effort is representative of a number of engineering applications which can capitilize on the sensitivity and specificity of the VER to define operator display demands with greater precision than most psychophysical or subjective measures. Since the human is the ultimate system through which displays and systems are processed, it seems eminently reasonable that we should utilize the human's physiology to "calibrate" the system and to establish standards. Such an application has been demonstrated by Regan et al.[10] If a checkerboard display of given color, intensity, contrast, etc., is presented to a subject, the amplitude of the steady state EP can be determined. If any one parameter of the display is changed, there is a corresponding amplitude change in the EP. For instance, if the display color is changed, the EP amplitude might go down. If, however, a "feedback" loop is established whereby the intensity of the display will increase whenever the EP amplitude decreases, the experimenter can bring the amplitude back up to previous levels. Thus, one can determine the intensity for a "green" necessary to make it produce the same EP as a "red." In effect, one has achieved a point of "subjective" equality (at least physiologically) without ever asking the subject. Such a technique offers broad promise for providing objectively determined standards which do not ignore the human.

Clinical Applications

Although the major thrust of our efforts is directed to operational utilization of the EP, it is impossible to ignore the clinical applications of this technique. It has already been mentioned that the VER can be used to measure visual acuity.[5] Similar techniques are available to measure visual and auditory thresholds in infants and mentally retarded individuals, as well as certain aspects of cognitive function.[3] Recent research has developed techniques for utilizing the VER as an adjunct in the diagnosis of multiple sclerosis,[11] certain brain tumors, learning disability, and even psychiatric disorders.[12] This has led in part to a Memorandum of Agreement between our laboratory and the Medical Center at Wright-Patterson AFB for cooperative research and clinical consultation. We now regularly receive referrals from the Neurology, Pediatrics and Mental Health clinics, and have begun to engage in clinical research with physicians from the Medical Center.

FUTURE DIRECTIONS

For the future, we see routine application of the VER technology in the Air Force for the types of human engineering applications described above. In other laboratories, most notably in the U.S. Navy, the potential of the VER is being tested for assisting in personnel selection and evaluation. Beyond these already implemented functions, we anticipate several developments which will dramatically expand the utility of the VER.

Single-event Evoked Responses

One of these involves the method used for signal-to-noise improvement. As long as we remain dependent on repetitive stimulation and ensemble averaging, the EP will have limited field application. Alternative techniques are already available and show great promise of allowing us to isolate the evoked response in a single stimulus presentation. Mathematical treatments such as principal component analysis, step-wise discriminant

analysis and coherence functions can be used to match a pre-existing template. More elaborate systems use matched filters or a combination of prefiltering and cross-correlation to determine when an evoked response has occurred. When these systems become operational, on-line evaluation of the subject's EEG will become possible without the artificial laboratory situation required by repetitive stimulation.

Endogenous Stimuli

Another major limitation of the EP as presently used is its dependence on an external stimulus event to serve as a "marker" for the beginning of a sampling period. In practice, this has required us to use discrete sensory events, although many situations of interest do not intrinsically lend themselves to such discontinuous stimulation (e.g., map-reading, photo-interpretation, comm[illegible] decision-making, etc.). In such c[illegible] one would like to know the precis[illegible] stant in which a meaningful stim[illegible] began to operate within the individual. Even if one could identify the point at which a sensation began in a given cognitive task, this still might not be the point at which the sensation became a perception and began to be processed by the individual.

Such a dilemma has caused us to begin searching for "endogenous" stimuli to use as triggers for the EP. If we can identify some event within the person which signals that the processing has actually begun, we could use that event to begin sampling the EEG. One of the most obvious of such endogenous stimuli involves the subject's own eye movements. Researchers have already established that the eye movements and fixations can be used to pinpoint meaningful events in the EEG which were otherwise uninterpretable. We are planning to use the precision offered by the Stanford Research Institute eye tracker to determine whether triggering off the initiation or termination of an eye movement will reveal micro-components of the EP which are missed when the external event is used as a trigger. It should also be possible to use the EP itself as a trigger for another EP. If we improve our capability to identify the early "sensory" events in the EP on a single stimulus, then we might use one of these events (such as the P_2) to trigger another sampling epoch. The added milliseconds of precision offered by this technique, as opposed to using the external event, might reveal a great deal more complexity and detail in the "processing" segment of the EP than we presently see in the P300 peak. Developments such as these will go far in reducing the apparent variability of the EEG between subjects, and further enrich the detail of the EP as a metric.

Human Engineering Test Battery

As a far-reaching goal, it is possible to conceive of standardized procedures for human engineering applications utilizing the EP and other psychophysiological and behavioral techniques. Some attempts at such a test battery have been made in the past, but these have been limited by the state-of-the-art in recording and analysis, and by the fact that adequate basic research in psychophysiological techniques had not yet been done. As we have seen, the research is now being done, at an accelerated pace. In addition, it is time to begin capitalizing on the enormous computer and analytical power now being developed fo bio-medical data. Such power allows us to conceive of many-channel EEG recordings, combined with other psychophysiological and behavioral measures. Such a multivariate approach has alread been used successfully in the development of a "neurometrics test battery" for the rapid assessment of neurological problems in children.[12] In this battery, 57 brain sites can be monitored during 50 different test items or "challenges," yielding as many as 85,000 measures in a test session lasting from 15 to 50 minutes. This enormous quantity of data is reduced by pattern recognition techniques to some 80 measures, yielding a complete neurological survey, examining everything from hyperactivity to drug effects. It is not at all inconceivable that such a test battery could be developed specifically for the type of human engineering and personnel applications described in this paper. The major advantages of such a system would be its objectivity, specificity, and, since it would deal with processes rather than simply products, its ability to be generalized from one design question to another. Added to the developments mentioned above, such a system should allow online evaluation of the operator, permitting assessment of fatigue, attention, psychological distress, or

other potentially dangerous states.

SUMMARY

With any development which shows considerable success in a defined area of application, it is easy to be overly optimistic about the future. We have allowed ourselves a degree of latitude in speculating where this newly applied metric will proceed in the future. However, we are not unaware of the difficulties which lie ahead, and we do not underestimate the magnitude of the problems to be solved. Workers in this area are operating at the frontier of technology in electronics, in mathematics, in medicine, and in psychology. Not all developments which now seem feasible will prove so. Yet, a hard appraisal of tradeoffs convinces us that the effort is worth the risk. If even a part of the apparent capability is achieved, it will be worthwhile.

The principal dangers in this approach lie not so much in the technical sophistication or difficulties involved, but in the possibility for misuse and overgeneralization. The EP is certainly no panacea for all design problems. It can never replace subjective report, and can never substitute for inadequate designs. If anything, it requires more care and more sophistication in experimental design than previous metrics. The increased precision and sensitivity is purchased at the cost of increased need for attention to detail and for experimental validation of interpretations. It is inevitable that mistakes will be made and misinterpretations will become an everpresent threat.

In spite of these possibilities, we believe that the VER technique has opened a door for a new kind of measurement approach in human engineering. The approach attempts to be functionally related to real world events, and to analyze process as well as product. It represents a bold attempt to provide a quantum increase in the precision of analysis. In summary, we feel the technique provides perhaps the first true microscope the human engineer has ever possessed.

ACKNOWLEDGEMENTS

The authors express their sincere appreciation to Dr. F. Gomer, Ms. D. Bach, Ms. J. Klug, and Ms. R. Renfroe for their assistance and dedication in the design, conduct, and analysis of the experiments reported here.

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